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Assessment of land use change and potential eco-service value in the upper reaches of Minjiang River, China

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Abstract: The remote sensing (RS) and geographical information system (GIS) technologies were adopted and a mathematic method was developed to evaluate the changes of ecosystem services in the upper reaches of Minjiang River-valley for providing advices to manage the ecosystem. The results showed that the land use change mainly occurred on forest, farmland and grassland. From 1986 to 1994, the area of farmland increased by 477% (60801 hm^2), while the area of forest decreased by 4.97% (89012.17 hm^2). From 1986 to 2000, the eco-service value of forest was degressive but that of farmland increased greatly as the increasing of planting area, while the total eco-service value decreased by 771.11×10^8 yuan RMB due to the rapid increase of population in this region. The driving force of eco-service change was also discussed in the paper. The nation policy of Natural Forest Protection Project has taken effect in preventing the decline of eco-services.

Keywords: Upper reaches of Minjiang River; Land use; Ecosystem service; Remote sensing

Introduction

The ecosystem services and the natural capital stocks that produced them are critical to the functioning of the earth's life-supporting system (Guo 2001). They contribute to human welfare directly or indirectly, and therefore represent part of the total economic value of the planet (Costanza *et al*. 1997). They include nutrient cycling, carbon income and expenses, air and water filtration, and flood amelioration (Costanza *et al.* 1997). However, these services are not recognized fully by human societies. The economic valuation of ecosystem services is becoming an effective way to understand the multiple benefits provided by them. Since 1990 numerous studies have been conducted to estimate the values of various ecosystem services. Some notable examples include assessment of the economic value of tropical forests (Peter *et al*. 1989; Tobias and Mendelsohn 1991; Bacilli and Mendelsohn 1992; Chopra 1993), evaluation of methods for estimating the economic value of different biological resources (Pearce and Moran 1994), economic incentives for biodiversity conservation (Mcneely 1993), economic valuation of protected area (Cacha 1994; Lacy and Lockwood 1994; Munasinghe 1994), and economic value of endangered species management (Hyde and Kanel 1993; Kramer and Munasinghe 1994; White *et al.* 1997). Guo *et al*. (2000) reported an assessment of ecosystem service for water flow regulation and hydroelectric power production and evaluated the ecosystem functions, services and values of Xingshan County of China. Zhao *et al*. (2004) assessed the ecosystem service value of Chongming Island based on land use change, China. Kremen (2005) elucidated what we need to know in managing ecosystem services. Yung (2004) presented a critical review on the neoclassical economic framework, tools used for economic valuation of ecosystem services and the economic welfare approach to collective decision-making, forming an ecological perspective. Amirnejad *et al.* (2006) evaluated the existence value of north forest of Iran and measured individual's willingness to pay basing on contingent valuation and dichotomous choice. Loomis *et al*. (2000) evaluated five ecosystem services of the Platte river using a building block approach developed by an interdisciplinary team. Sell *et al*. (2006) analyzed market actors' decision criteria related to engagement in tropical forestry projects that provided environment services. Christopher *et al* (2005) demonstrated a framework for the spatial modeling of ecosystem services production in watersheds based on the conceptualization that agricultural watershed as complex adaptive human ecosystems. Pattanayak (2004) addressed the neglected, but critical, question of the importance of watershed services to farming communities in southeast Asia, by developing a conceptual framework and using household level economic and environment data to illustrate its empirical tractability and offered lessons for researchers at all stages of data collection and analysis and a research agenda for enhancing our toolkit for policy analysis. Curtis (2004) used a new approach that used a surrogate market and the combination of a multiple criteria analysis and a Delphi panel to assign weights to the attributes to value ecosystem goods and services in Australia.

The upper reaches of Minjiang River-valley is a key region for eco-environment rebuilding according to National Eco-environmental Renovating Scheme of China (http://www.coi.gov.cn/zrbhq/law6.htm). It is necessary to evaluate the changes of ecological services to constitute accurate policy for sustaining development. In this study, on the basis of

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about 25 years land use change and the achievements of other researchers, the eco-services of the upper reaches of Minjiang River had been evaluated through the ecosystem service value unit area of Chinese terrestrial ecosystem and the normalized difference vegetation index (NDVI).

Methods

Description of the upper reaches of Minjiang River

The upper reaches of Minjiang River-valley lies between 31°26′–33°16′ North latitude and 102°59′–104°14′ East longitude, with a length of 340 km and an area of about 23 000 km^2 across Songpan, Heishui, Mao, Li, and Wenchuan counties in exact correspondence to the governing range of the five counties (Fig. 1). It is a green-reservoir and eco-fence of the Chengdu Plain, and one of the water-resource areas of the Changjiang River. Meanwhile, it is also a typical mountainous region with apparent upland ecosystem vulnerability and sensitivity. Located on the eastern edge of Qinghai–Tibet Plain, the topography of the area is characterized by the complex distribution of hills and valleys, ranging in elevation from 700 to 6 260 m with average elevation difference above 1 000 m. Its temperature is obviously related to latitude and altitude with a vertical declining rate of temperature about 0.46ºC/100m. Its northern area with elevation above 2 000 m is extreme cold and has annual precipitation 730–840 mm; the southern area is drought river-valley with elevation 1 200–2 000m and annual precipitation 420–566 mm. More than 80%–90% of the annual precipitation falls from May to October. The total population in this region in 2000 was 385 300 and mainly concentrated in river-valley area.

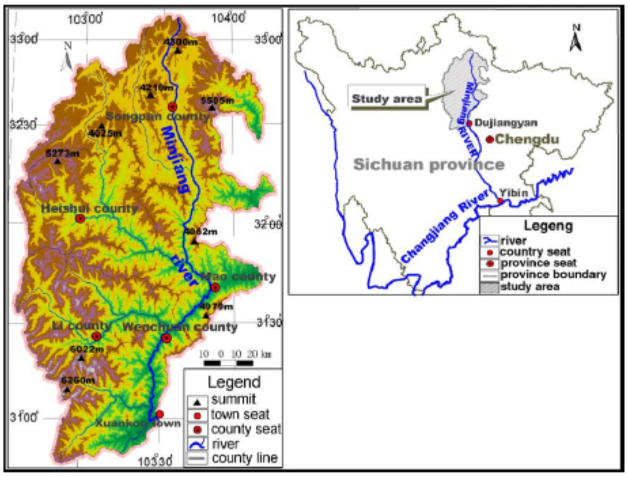

Fig.1 Location map of the upper reaches of Minjiang River showing the relationship between the study area, Sichuan Province, and the Changjiang River, as well as displaying the relief (Li *et al.* 2006).

Data

The basic data used in this study include: (1) remote sensing (RS) data, TM data (September 1986, 1994 and 2000); (2) the ecosystem service value unit area of China terrestrial ecosystem (Xie *et al*. 2003,); (3) NDVI index of China in 1998 (http://www.naturalresources.csdb.cn) (Table 2); (4) social economic data, from Annual Statistics of Aba eparchy in Sichuan Province.

Firstly the image was revised of radiation and calibrated geometry and all data had the unified coordinate systems (Albers Equal Area system with original longitude 105°E, original latitude 0°, double-standard parallel of 25°N and 47°N, Beijing 1954 geodetic datum and Krassovsky ellipsoid). Secondly the images were interpreted by user-computer interactive interpreting method through ERDAS IMAGINE8.6 and validated the outcome through confusion matrix and Kappa index, with an interpreted precision of 78.2%. Finally the interpreted results were switched to vector datum and grid needed.

Revising the ecosystem service value unit area of China terrestrial ecosystem

For evaluating the ecosystem value, the common method is to integrate the researches in different territory and conclude the main function of ecological process and ecosystem value. Costanza *et al*. (1997) created the theories and methods on evaluating ecosystem value clearly from scientific purport. However, when it was applied to concrete area, it would produce biggish warp. Xie *et al* (2003) constituted the ecosystem service value unit area of China terrestrial ecosystem based on questionnaire investigation from about 200 ecological scholar and some achievements.

In this study, the ecosystem services were divided into purification of air, climate stability, flood and drought mitigation, soil generation and soil fertility, decomposition of waste, biodiversity protection, food production, ecosystem goods, aesthetic and cultural (Table 1). The climate stability included the disturb adjustment mentioned by Costanza (1997); soil generation and soil fertility also included soil generation, nutrition cycle, erosion control, ecological functions; biodiversity protection included pollination, biology control, habitats and gene resource. Ecosystem service value unit area is the latent ability of the ecosystem services produced by ecosystem. It is defined as the economic value produced by 1-hm^2 farmland in China. Thus, Table 1 can be transformed to the table of eco-service value in the same year. Through contrast analysis, 1 eco-service value unit area equal to 1/7 of average foodstuff market value in China (Xie 2003).

Table 1 provides an average unit price of China. However, there exist affinities between ecosystem service value and biomass. Proverbially, the bigger the biomass is, the higher the ecosystem service value is. The NDVI is an index that provides a standardized method of comparing vegetation greenness and biomass between satellite images, and it can be calculated by the following equation.

$$\mathrm{NDVI} = \frac{\text{near IR} - \text{red band}}{\text{near IR band} + \text{red band}} \tag{1}$$

The index values range from -1.0 to 1.0, but vegetation values typically range between 0.1 and 0.7. Higher index values are associated with higher levels of healthy vegetation cover, whereas clouds and snow may cause index values near zero. NDVI can be used as an indicator of relative biomass and greenness (Boone *et al.* 2000; Chen 1998, Loris and Damiano 2006; Freitas *et al.* 2005).

Table 1. Ecosystem service value unit area of China terrestrial ecosystem

Item	Forest	Grass-land	Farm-land	Marsh	Water	Waste-land
Purification of air	3.5	0.8	0.5	1.8	0	0
Climate stability	2.7	0.9	0.89	17.1	0.46	0
Flood and drought mitigation	3.2	0.8	0.6	15.5	20.38	0.03
Soil generation and soil fertility	3.9	1.95	1.46	1.71	0.01	0.02
Decomposition of waste	1.31	1.31	1.64	18.18	18.18	0.01
Biodiversity protection	3.26	1.09	0.71	2.5	2.49	0.34
food production	0.1	0.3	1	0.3	0.1	0.01
Ecosystem goods	2.6	0.05	0.1	0.07	0.01	0
Aesthetic, cultural	1.28	0.04	0.01	5.55	4.34	0.01

Table 2. The average NDVI of China and the upper reaches of Minjiang River

	Jan.	Feb.	March	April	May	Jun.
China (average)	0.014	0.015	0.017	0.022	0.039	0.052
Minjiang (average)	0.129	0.125	0.122	0.176	0.355	0.357
	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
China (average)	0.059	0.059	0.054	0.032	0.023	0.016
Minjiang (average)	0.306	0.360	0.388	0.217	0.185	0.172

So, premising a linear relationship between ecosystem service value and biomass, the equation can be created as follows:

$$Q_{\mathrm{ij}} = \frac{NDVI_m}{NDVI_n} \times p_{ij} \tag{2}$$

where, Q_{ij} is the unit price after revisal, $NDVI_{\mathrm{m}}$ the average value of upper reaches of Minjiang; $NDVI_{\mathrm{n}}$ the average value of China, and p_{ij} the unit price before revisal; i=1,2,3,…9, separately denote the ecosystem services; j=1,2,3…6, separately denote the land use types.

Evaluating the ecosystem service value

Basing on Table 1 and the value produced by the unit area of farmland, we can calculate the ecosystem service value by the Equation (3) as bellow:

$$P_a = 1/7\sum_{i=1}^{n}\frac{V}{M} \tag{3}$$

where, P_a is the economic value of one unit ecosystem service price, V the economic value produced by every farm, M the area of every crop, and n the category of crop.

$$P_{ij} = e_{ij}\ P_a \qquad (i=1,2,3,\ldots,9;j=1,2,\ldots6) \tag{4}$$

where, P_{ij} is the economic value of i ecosystem services of j ecosystem and e_{ij} is the unit value of ecosystem services in upper reaches of Minjiang River.

Basing on the area of every ecosystem and the economic value of unit value, we can calculate the total economic value by the following equation.

$$V = \sum_{i=1}^{9}\sum_{j=1}^{6} A_j Q_{ij} \tag{5}$$

Where, V is the total value of ecosystem services, and A_j is the area of every ecosystem.

Results

The economic value / unit area of economic value in the upper reaches of Minjiang River

For evaluating the economic value of food, we mainly calculated the economic values of the paddy, legume, potato and vegetable that are planted broadly by the price of 2001 (Table 3). The paddy includes corn, rice and wheat and the legume mainly is Soya. From Table 3, we can see that the area of paddy is biggest, accounting for about 60% of the total area, followed by that of vegetable, accounting for about 60% of the total area, but the economic value of vegetable is evidently higher than that of paddy.

Table 3. The area and economic value of food in upper reaches of Minjiang River during 2001

Food species	Area (hm^2)	Value in 2001 （10^8yuan RMB）
paddy	13136.00	88.0
legum	3156.60	17.2
potato	973.00	24.7
vegetable	4554.10	105.9

Data source：statistical almanac of Aba eparchy; the economic statistical handbook of 2001.

According to Table 2 and Eq. 2, we calculated the economic value unit area of ecosystem services in upper reaches of Minjiang River, and the results are listed in Table 4.

Table 4. The economic value unit area of ecosystem services in upper reaches of Minjiang River

Item	Forest	Grassland	Farmland	Marsh	Water	Wasteland
Purification of air	24.32	5.56	3.47	12.51	0.00	0.00
Climate stability	18.76	6.25	6.18	118.81	3.20	0.00
Flood and drought mitigation	22.23	5.56	4.17	107.69	141.60	0.21
Soil generation and soil fertility	27.10	13.55	10.14	11.88	0.07	0.14
Decomposition of waste	9.10	9.10	11.39	126.31	126.31	0.07
Biodiversity protection	22.65	7.57	4.93	17.37	17.30	2.36
food production	0.69	2.08	6.95	2.08	0.69	0.07
Ecosystem goods	18.06	0.35	0.69	0.49	0.07	0.00
Aesthetic, cultural	8.89	0.28	0.07	38.56	30.15	0.07

The land use change in the upper reaches of Minjiang River

Fig. 2 shows the land use of the upper reaches of Minjiang River in 1986, 1994 and 2000.. From 1986 to 1994, the area of farmland increased by 60801 hm^2, approximately accounting for 477% of the farmland area of 1986, the area of forest decreased by 89012.17 hm^2 (4.97%), the proportion of grassland increased by 31958.39 hm^2 and the wasteland proportion had not evident change. The change between 1994 and 2000 is not evident. Therefore, it can be concluded that the land use change was mainly occurred on forest, farmland and grassland

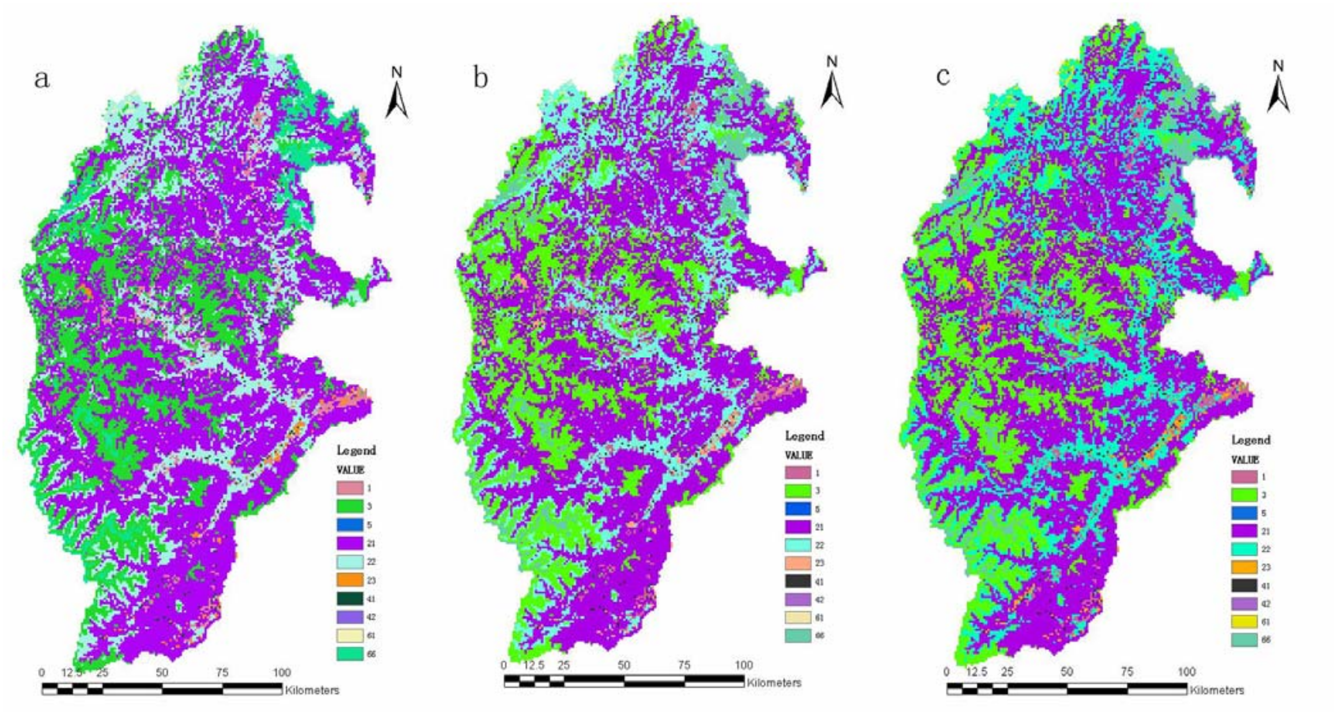

Fig. 2 the land use of the upper reaches of Minjiang River in 1986(a), 1994(b) and 2000(c)
1) farmland; 21) Forest land; 22) Shrub, 23)orchard; 3) grassland; 41)river; 42) lake; 5)build up；61) marsh; 66) hungriness.

Table 5. the land use in the upper reaches of Minjiang River during 1986 to 2000

Land type	The area of different land types (hm^2)		
	1986	1994	2000
farmland	12737.51	73538.51	73682.6
forest	1789817.41	1700805.24	1696639.96
water	20165.68	20186.21	20226.34
marsh	3261.41	3238.81	3238.77
grassland	524791.66	553754.7	556750.05
wasteland	105029.95	104280.15	105265.9

The ecosystem service value change

Basing on Eq. (5), we calculated the changes of ecosystem service value in different time (Table 6). The result showed that forest is the main proportion of ecosystem services, followed by grassland, but the ecosystem service value of forest is degressive from 1986 to 2000. From 1986 to 1994, the ecosystem service value of forest decreased by 1085.11×10^8 yuan RMB. The ecosystem service value of farmland increased greatly (234.91×10^8 yuan RMB) because of the increasing of planting area from 1986 to 2000. The total ecosystem services value decreased by 771.11×10^8 yuan RMB during 1986 to 2000.

Table 6. ecosystem service value of different land types in upper reaches of Minjiang River during 1986 to 2000

Land type	Ecosystem service value (10^8yuan RMB)		
	1986	1994	2000
farmland	49.13	283.53	284.04
forest	21819.07	20733.96	20683.16
water	517.22	517.73	518.76
marsh	114.08	113.31	113.31
grassland	2119.81	2236.84	2248.93
wasteland	24.63	24.44	24.69
total	24619.31	23885.37	23848.20

Discussion

Analysis of the driving force of ecosystem service change

The ecosystem services had changes during 15 years (1986-200), and the change trend was in accordance with woodland coverage

change. The driving force for the changes is mainly related to the impact of social economy. The increasing pressure of human on land led to rapid changes of land use. More and more Forests were cutting down, thus resulting in a further degradation of eco-services. As was recorded in Marco Polo Travel Notes, 600 years ago the main stream and branches of Minjiang River were covered by boundless forests with a coverage of 50%, however, in the early 1950s, the forest coverage declined to about 30%, which revealed a general degradation trend of eco-environment in this region. Nevertheless in 1960s, the mass steel-making movement and the great leap forward of production resulted in a rapid decrease of forest coverage (Li *et al.* 2006). Up to 1980, the forest coverage of this region had been down to 18.80% (Lu 1999). In late 1980s, forestation came to be regarded as an important forestry eco-industry. However, because the financial income of Songpan, Li, and Heishui counties in upper reaches of Minjiang River mainly come from wood industry, the overexploitation of forests has not been stopped basically. Li (2003) reported that the flow in Minjiang River is well correlative with woodland coverage. When woodland coverage is below 18.46%, the mainstream of Minjiang River perhaps dries up during dry season, while peak flew will turn bigger in flood season. In fact, in late 1990s, the cut-off stream had continuously appeared in Minjing River (Ding 2001). The datum of Aba records showed that about 150 thousand people live in upper reaches of Minjiang River in 1950s. The population in this region was up to 334.3 thousands in 1986 and reached 363.8 thousands in 1994. According to the nose-count investigation in 2000, the population of this region had increased to 380.6 thousand. The analysis of correlation between farmland, population and ecosystem service value showed that there is a negative correlation between the population and eco-services and the farmland and eco-services (Table 7). Population has a positive correlation with farmland.

Table 7. The correlation between population, farmland and ecosystem service

		population	service	farmland
population	Pearson correlation	1	-.948	.934
	Sig. (2-tailed)		.207	.232
	N	3	3	3
eco-Service	Pearson correlation	-.948	1	-.999*
	Sig. (2-tailed)	.207		.026
	N	3	3	3
Farmland	Pearson correlation	.934	-.999*	1
	Sig. (2-tailed)	.232	.026	
	N	3	3	3

The effect of policy

After super flood in 1998, the execution of the policies of Natural Forest Protection and Grain for Green was beneficial to the restoration of forest in the upper reaches of Minjiang River. From Table 5 and Table 6, we can see that the area of forest and its ecosystem service value in 2000 was only 4165.48 hm^2 and 50.8×10^8 yuan less than in 1994, respectively. This demonstrated that the national policy had taken effect on preventing the degradation of eco-services. However, due to lack of the remote sensing image of 1998, whether the degradation trend can be reversed completely requests a further supervision, meanwhile, eco-environment is also closely related to other natural geographical aspects

Conclusion

This study focused on the ecosystem services in a typical mountainous valley in the upper reaches of Minjiang River. A mathematic method was developed to analyze eco-service value in mountainous region under the support of RS and GIS. The results showed that from 1986 to 1994 the area of farmland increased by 477% (60801 hm^2), while the area of forest decreased by 4.97% (89012.17 hm^2); the proportion of grassland had a litte increase and the wasteland proportion had no evident change. From 1986 to 2000, the eco-service value of forest was degressive, especially during 1986 to 1994 (decreased by 1085.11×10^8 yuan), but the eco-service value of farmland had increased greatly (234.91×10^8 yuan) because of the increase of planting area. The total ecosystem service value was decreased by 771.11×10^8 yuan RMB during the 15 years (1986-2000), which attributes mainly to the repaid increase and requirement of population in the region. In a certain degree, the ecosystem service value changes reflected the eco-environment's quality. Through the contrast of ecosystem services value in different time, it suggests that the land use should be regulated and the policies of Natural Forest Protection and Grain for Green should be well-implemented to optimize the land cover. The family planning policy must also been executed in the minority territory for the sustaining development.

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